GEOTECHNICAL SERVICES

INITIAL GEOHAZARDS EVALUATION AND GEOLOGICAL STUDY: BEARTOOTH HIGHWAY, U.S. 212, WYOMING

Prepared for
Department of Transportation
Federal Highway Administration
Central Federal Lands Highway Division
Lakewood, Colorado

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WCFS Project No. FHAT0011

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This report presents an overview of regional geology and a discussion of geologic hazards, including criteria for investigation and design for part of the Beartooth Highway (U.S. 212) in Wyoming from MP 24.5 to MP 43.2 (the Wyoming/Montana state line), where improvements are proposed. Proposed improvements include widening the existing roadway from 5.487 m (18 feet) to 12.802 m (42 feet) subgrade width and 9.754 m (32 feet) pavement width, some straightening of curves, and modification of some pullout areas. The project area is shown on Figure 1.

A field reconnaissance was conducted by Sam Holder and Gary Strike of the FHWA and Scott Anderson of Woodward-Clyde Federal Services on August 17 and 18, 1998. The recommendations presented in this report are based on observations from this trip, notes from the FHWA field review on June 23-25, 1998, and review of aerial photographs provided by the FHWA.

In addition to the five sites of potential geologic hazards identified by the FHWA in the Scope of Work, we identified a sixth location of potential geologic hazard between approximate Stations 60+500 and 62+000. With the exception of these six sites, the proposed reconstruction appears to be free of significant geologic hazards. The seismicity of the site is not currently well understood and should be studied further in subsequent investigations, as discussed in Section 2.

This work is performed under Contract DTFH68-97-D-00003, Task Order DTFH68-98-T-00011.

The following description of the regional geology and geologic history of the Beartooth highway area is largely based on *The Beartooth Highway* by H.L. James, Montana Bureau of Mines and Geology, Special Publication 110, October 1995.

2.1 REGIONAL GEOLOGY

The Beartooth highway leads from Cooke City, Wyoming to Red Lodge, Montana, and passes through the southeastern portion of an area known as the Beartooth uplift. This uplift resulted from the mountain building of the Laramide orogeny and covers an approximately 7,700 square kilometer area. The uplift area is 1,200 to 1,500 meters higher than the surrounding basins, and relief within the uplifted area varies from 1,675 meters msl along the lower Stillwater River, to 3,901 meters msl at Granite Peak, Montana. The Beartooth uplift generally consists of glaciated Precambrian granite and metamorphic rock which is overlain in places by Tertiary volcanics and occasional flat-lying sedimentary rock remnants.

The Beartooth uplift can be divided into three blocks, the North Snowy Block, South Snowy Block, and the Beartooth Block. These three blocks are separated by fault zones and a structural depression. The Beartooth highway passes through the eastern portion of the Beartooth block. The Beartooth block is bounded on the east and northeast by the Beartooth thrust fault, the southwest by the Clarks Fork normal fault, and the northeast by the Mill Creek normal fault, which is the boundary between the Beartooth block and the North Snowy block. The Cooke City Zone, a northwest trending structural depression connecting the Mill Creek fault and the Clarks Fork Fault, separates the Beartooth block from the South Snowy block.

2.2 GEOLOGIC HISTORY

The center of the Beartooth uplift area consists of Precambrian aged crystalline rocks which have been dated to be at least 3.96 billion years old. After the formation of these crystalline rocks, numerous mafic dikes were intruded along fractures and the rocks were eroded to a nearly flat surface.

A thick (1,200 meter) sequence of sedimentary rocks was deposited during the Cambrian period. The basal unit of this sedimentary sequence is known as the Flathead Sandstone Formation. This formation consists of quartzitic sandstone and commonly forms the small sedimentary rock plateaus which presently exist on the uplift. Deposition of sedimentary rocks continued until the Cretaceous period; the total thickness of sedimentary rocks deposited has been estimated to be on the order of 3,700 meters.

Crustal deformation associated with the Laramide orogeny during the Cretaceous period resulted in the uplift of the Beartooth area, as well as faulting, thrust faulting, and tilting and folding of rocks. The uplift pushed Precambrian crystalline rocks through the Cambrian sedimentary rocks. This resulted in sedimentary rocks on the uplifted block which were raised horizontally, and steeply dipping beds of sedimentary rock surrounding the uplift zone.

Uplift of this area continued through the Tertiary era. During this time, intrusive and extrusive igneous rocks were deposited over the South Snowy block, and much of the horizontally uplifted sedimentary rocks were eroded. Only a few remnants, such as Beartooth Butte, which is north of the highway near station 41+000, remain of these sedimentary rocks.

Alpine glaciation covered much of the Beartooth uplift, except for a few areas in the east and southeast, during the Pleistocene period. Glacial processes have resulted in the majority of landforms which currently exist at the Beartooth uplift area.

2.3 SEISMICITY

Current Understanding

The project site is located in northwest Wyoming within the Middle Rocky Mountains. The Rocky Mountains define the eastern margin of the broad North American Cordilleran orogen in the western U.S., which developed in late Mesozoic time. The Middle Rocky Mountains are bounded by the Yellowstone Plateau to the west, the Great Plains to the east, the Northern Rocky Mountains to the north and the Wyoming Basin to the south. The site is located approximately 20 to 40 km east of Yellowstone National Park and the eastern edge of an active zone of faulting and seismicity known as the Intermountain Seismic Belt.

The earthquake history of the site, similar to much of the western U.S., has only been known since the region was first settled, a period of approximately 100 years. Due to sparse population and seismograph station coverage prior to 1960s, only larger earthquakes were detected and/or felt. As the number of seismograph stations increased across the region, especially in the vicinity of Yellowstone in the 1970s, an increasing number of earthquakes of smaller magnitudes have been detected.

A historical seismicity catalogue compiled for a nearby project is summarized on Figure A-1. The site region was selected to include seismic sources capable of generating strong ground shaking in the Bighorn Basin, but it is believed to also be representative of the Beartooth Highway project site area. Primary data sources used in the historical seismicity compilation include the Decade of North American Geology (DNAG) catalogue for the period from about 1800 to 1985; the Stover, Reagor and Algermissen (SRA) catalogue compiled by the National Earthquake Information Center (NEIC) for the period 1534 to 1985; the University of Utah historical seismicity catalogue for the period 1886 to 1995; and the NEIC Preliminary Determination of Epicenters for the period from 1900 to 1996. These sources include the time period of an apparent earthquake that impacted the Top of the World store, as discussed subsequently.

Based on the historical record, the highest concentration of events is located southwest of the project site in Yellowstone National Park, possibly the most seismically active area within the interior western U.S. The largest earthquake in the vicinity of Yellowstone, was the 1959 surface-wave magnitude (M_S) 7.5 Hebgen Lake earthquake, which caused significant highway damage. The largest earthquake to occur within Yellowstone National Park was the 30 June 1975 M_L 6.1 Norris Junction earthquake.

Recently, an earthquake may have impacted the Top of the World store located on the north side of the Beartooth Highway, about half way between the Bear Lake and Island Lake Campgrounds, shown on Figure 1. The owner of the Top of the World store has told Mr. Gary Strike of the FHWA, that in the spring of 1995 or 1996, when he returned to the store after the winter closure, he found broken mortar in the front steps, fallen ceiling panels, and merchandise fallen off of shelves. These observations and the level of impact are consistent with earthquake shaking with a

Modified Mercalli intensity of at least V, and possible as high as VII. These intensities could probably not have been generated by an earthquake with Richter Magnitude less than about 5.0, even if the epicentral distance was small. It is the store owner's impression that an earthquake was felt in Cooke City, about 30 km to the northwest, during the winter. This may have been the same event that caused damage at the Top of the World store.

It is not clear that any of the events shown on Figure A-1 would have caused the observed damage at the Top of the World store. It is possible that the event had not yet been included in the historical data bases. Up to date searches should be performed in subsequent investigations.

The nearest known fault is a fault known as the Top of the World fault, which strikes parallel to the highway in the valley near the Top of the World store. The Top of the World fault trace is probably within a few hundred meters of bridge structures over Little Bear Creek. We are not currently aware of evidence of activity on this fault, however, activity on this fault could explain the observations of high intensity shaking at the Top of the World store. Potential activity of this fault would significantly impact design criteria for bridges and other structures in this area.

AASHTO Bridge Design Specifications

The acceleration coefficient is about 0.075 in the project area, according to AASHTO *LRFD Bridge Design Specifications*, 1997 revised, Figure 3.10.2-1,. The figure presents results of the 1988 *U.S. Geological Survey NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* for the western U.S. and may not accurately reflect the level of seismicity in the project area.

Future Investigation Needs

To reconcile the observation of apparent seismic shaking at the site, the recent survey of seismic history in the Big Horn basin area, and the AASHTO Bridge Design Specifications, and to establish appropriate seismic design criteria, we recommend future investigations to include the following tasks:

1. Conduct a literature search for potentially active geologic fault structures within about 20 to 50 km of the site, with particular emphasis on structures which could have generated the observed impacts at the Top of the World store. This work should include communication with the Top of the World store owner and Yellowstone National Park personnel.
2. Conduct a historical seismicity search for the area within about 50 to 100 km of the site.
3. Develop design ground motion based on background seismicity and occurrence of a random earthquake, or potential activity of identified geologic fault structures.

3.1 SITE 1: STATION 39+800 TO 40+000

Existing Condition

The existing alignment crosses a slope of approximately 1:4 (vertical:horizontal) in this area. The slope is hummocky and apparently unstable, the road has notable dips in grade, and pavement has been repaired (Figure 2). Silty and clayey colluvial soil imply that bedrock is a silty shale. Surface drainage from the slope above the road is collected in an unlined toe ditch which drains easterly to a cross culvert. Thick, green grasses and plants downslope of the road suggest drainage is poor.

Potential Hazards

Potential geologic hazards include excessive settlement and landsliding. The indications are that the foundation conditions in this area include wet clayey silt and weathered shale bedrock, which will be relatively weak and compressible. Furthermore, there is apparently an existing shear surface beneath the roadway. Placement of fill could reactivate or accelerate movement on this surface.

Investigation Recommendations

Investigation in this area should include test holes to evaluate the existing roadway foundation and the foundation of proposed fill outboard of the existing roadway (see recommendations below). At a minimum, two standpipe piezometers and one slope inclinometer should be installed to monitor water level and potential slope movement. Continuous soil core sampling may prove to be useful for identifying existing shear surfaces in soil and weathered bedrock. We recommend the driller be prepared for this type of drilling and sampling.

Preliminary Design Recommendations

It is proposed by the FHWA to maintain the existing alignment and grade in this area. Based on the site reconnaissance reported herein, we offer the following preliminary design recommendations:

1. Avoid cutting the inboard slope. It is already oversteepened and probably has a low margin of stability.
2. Widen by placing fill on a prepared foundation. Use granular fill derived from excavation in the igneous rocks east of the site as much as possible. Subsurface drainage should be incorporated in the embankment if free draining materials are not used.
3. Provide improved surface drainage using toe ditch drains, possibly lined, and cross culverts.
4. Use results of investigation and instrumentation data to develop final design of embankment and drainage.

3.2 SITE 2: STATION 41+600 TO 42+000

Existing Condition

The road is on a cut and fill section through this area, as shown on Figure 3. The road travels around a sharp outside corner near Station 41+600 and is relatively straight from 41+700 to 42+000 (see Figure 1). Bedrock is granite gneiss. The rock slope between 41+600 and 41+700 is about 25 m high and the lower 15 m is cut slope. The cut slope presents a very high rockfall hazard. Large blocks have loosened and their release appears imminent. The rock quality appears to improve about 10 to 30 m in from the rock face on the corner, as indicated by greater joint spacing, less iron staining, and larger talus (on the slope below).

The rock slope between 41+700 and 42+000 is about 30 m to 50 m high. For most of this length there is an apron of more weathered rock and flatter slope angle near the toe of the slope. The existing rock cut is within this apron.

Potential Hazards

The potential geologic hazard at this site is rock slope stability and rockfall from the cut slope, as discussed above.

Investigation Recommendations

We recommend the investigation be designed to evaluate the joint patterns and rock quality of rock outcrop above the road and the bedrock profile beneath the road. Detailed geologic mapping of the rock outcrop should be conducted. Because the existing rock cut appears to have numerous blast-induced fractures, the size of the potential cut here is large, and there appears to be some improvement in rock quality behind the existing face, the program should include two or three core holes on the rock outcrop above the road. The investigation plan should be finalized after the site is surveyed and topographic mapping above and below the road has been generated.

Test holes should also be drilled along the centerline and outboard shoulder of the road between about 41+700 and 42+000 to evaluate foundation conditions for walls or half bridges. Seismic refraction surveys should be conducted to extrapolate information from the test holes. Seismic refraction is probably the best geophysical method for locating bedrock at this site.

Preliminary Design Recommendations

This section of highway presents the most difficult conditions for widening. Our preliminary recommendation is for excavation between about 41+600 and 41+800. A blasting plan submittal should be required prior to construction and it should be reviewed by a qualified engineer or geologist. Rock bolts of about 4 to 6 m length will likely be required to support the excavation. Ground anchors may also be required. We do not recommend building retaining walls or bridges beneath such a hazardous slope.

Conditions for rock cut and for MSE wall construction improve between approximate stations 41+800 and 42+000. The existing rockfall hazard is less in this area. It appears that a partial width rock cut could be made within an apron of weathered rock without adversely affecting the stability of the higher rock face. However, from a constructability standpoint, it may be desirable to remove the entire apron, or nothing at all. It also appears that an MSE wall or half bridge could be constructed on the outboard side of the road to accommodate the increased road width and a pullout for waterfall viewing. It may be practical to found the MSE wall on bedrock.

3.3 SITE 3: STATION 53+400 TO 55+000

Existing Conditions

This relatively long stretch of road is above timberline and traverses a slope which gently slopes to the west. Granitic bedrock, which appears to have been scoured by glaciers, outcrops above and below the road (Figure 4). The road has several cut and fill sections of low to moderate height, and several small radius curves within the bedrock outcrop.

Most of the rock is fairly massive granite, with typical joint spacing on the order of 0.5 to 3.0 m. Prominent joint sets include a low-angle set, which generally dips into the cut and two near vertical sets which form part of the existing rock face.

Potential Hazards

Rock slope stability and rockfall are the potential geologic hazards at this site if the road is widened and straightened as planned. This hazard will likely be low because of the generally good rock quality and favorable joint orientations.

Investigation Recommendations

The investigation should include surface mapping of the rock outcrop to identify joints and joint spacing for design of rock cut slopes. Test holes may also be desired through existing fills to evaluate foundation conditions. Standard investigation procedures should suffice.

Preliminary Design Recommendations

Rock slopes can probably be designed so as not to require reinforcement, but care will need to be taken to provide a natural looking rock face. A blasting plan submittal should be required prior to construction and it should be reviewed by a qualified engineer or geologist. It will likely be necessary to create some large, fresh fracture faces, and staining with eonite or equivalent should be considered. Because of the variability in the road bearing and possible variability in joint orientations, the desired rock slope design may vary throughout this site.

Much of the material generated from the cut may be too large to be good highway fill material without further splitting or crushing. By comparison, the rock at Station 41+600 to 42+000 is more fractured and weathered, and a cut through this area would probably generate material that could be used more readily in road fill.

3.4 SITE 4: STATION 57+100 TO 57+300

Existing Conditions

The road climbs above a broad plateau with three hairpin turns, Site 4 is located near the lowest turn where the upper and lower roads are closest together, as shown on Figure 5. These switchbacks are highly visible from below. This is also a heavy snowdrift area and guardrail is not desired.

The bedrock is highly fractured in this area. It appears to outcrop in a few places above and below the road, and is probably at shallow depth where it does not outcrop.

Potential Hazards

The potential geologic hazard at this site is slope instability. This potential is greatest above the road, and cutting is not recommended for this reason. There would be little risk of instability for a fill slope below the road, however the fill slope would probably not catch the existing ground before the shoulder of the lower road, and it would be highly visible.

Investigation Recommendations

Investigation at this site should include mapping of bedrock outcrop on the slope, test holes from centerline and the outboard shoulder, and a seismic refraction survey. The focus of the investigation should be on identifying the location of the bedrock contact and the excavatability of bedrock near the contact.

Preliminary Design Recommendations

Our preliminary design recommendation is for an MSE retaining wall outboard of the current road shoulder. Although bedrock is shallow, it is probably weak enough and fractured enough to allow easy excavation and construction of the wall on a relatively uniform bedrock foundation. The toe of the wall would probably catch near the toe of the existing fill slope, so the wall would not impact the natural slope below the fill.

Excavation of the inboard slope is not recommended because of the poor rock quality. An engineered retaining wall would probably be required to support the cut slope.

3.5 SITE 5: STATION 67+250 TO 67+550

Existing Conditions

The road traverses the top of high, steep talus slopes. At least two CCC dry stack walls have failed below the road, causing road failure. Two relatively new gabion walls exist near both ends of the site. Mortared stone walls are also in place. The bedrock is closely fractured where it outcrops below the road and appears not well suited for major structure foundations without prior reinforcement. The site is shown on Figure 6.

There is currently a low cut slope above the road, and the natural slope behind the cut is relatively gentle. The natural slope is covered by alpine tundra and the cut slope has very little vegetation.

Potential Hazards

The geologic hazard is that existing or new walls or structures are undermined by erosion and raveling of the talus slope, or slope failure below the walls. This is judged to be a relatively high hazard, as there is evidence of this happening in the past.

Investigation Recommendations

We recommend drilling near the existing walls to evaluate their foundation conditions and drilling 2 or 3 supplementary test holes along the outboard shoulder where it is close to gullies and where MSE walls may be desired. We also recommend the bedrock outcrop be mapped. Mapping should include outcrop location, rock quality, and discontinuity characteristics and orientation.

Preliminary Design Recommendations

We understand that for aesthetic and alignment reasons it is desired to widen the road on the outboard shoulder. It is our opinion, based on our site reconnaissance, that this would require construction of large bridge or wall structures with reinforced foundations. Consequently we offer the following preliminary design recommendations:

1. Do not move the existing outboard shoulder outboard more than about 5 feet.
2. Plan to replace gabion walls with keyed in MSE walls, unless investigation shows walls are on strong bedrock foundation.
3. Gain additional width by moving right. Minimize cut if desired by increasing grade elevation.

3.6 SITE 6: STATION 60+500 TO 62+000

Existing Conditions

There are four sharp hairpin turns in this area and part of each hairpin turn encroaches on the top of steep east and west facing slopes, as shown on Figure 7. The top of the west facing slope has been stabilized, with varying success, with dry stack and masonry walls.

Potential Hazards

The geologic hazard is that existing or new walls or structures are undermined by erosion and raveling of the talus slope, or slope failure below the walls. This is judged to be a relatively high hazard, as there is evidence of this happening in the past. There is also the potential for headward erosion of a drainage gully on the upper curve, which is caused by runoff from the road. The stability of this gully could be improved considerably by installation of riprap.

Investigation Recommendations

The investigation plan should be developed after a proposed road alignment is selected through the curves. The investigation should focus on foundation conditions for fill or MSE walls, generally at the exit of each curve. Test holes should be drilled at each of these locations. The condition of dry stack and masonry walls, and their foundations should be observed and mapped. If the outboard shoulder is to encroach on any of the existing slope walls, the foundation of these walls should be evaluated by geophysical methods or drilling.

Preliminary Design Recommendations

It appears that the road can be widened and an adequate radius maintained by exiting each corner wider on fill sections or, optionally, on MSE walls. This would not require moving the outboard shoulder outboard within the turns and is our preliminary design recommendation for this area.

If the outboard shoulder of the road is to stay where it is, none to relatively minor stabilization of the gullies and dry stack and masonry walls would be recommended. Where necessary, wall foundation stabilization could possibly be accomplished without removing and replacing the walls by installation of micropiles or concrete sills in front of the toe of the walls to control headward erosion. Where stabilization in place is not practical, it may be necessary to replace the walls with walls buried to greater depth or founded on bedrock. Walls that are in poor condition should be replaced.

If the shoulder is moved outboard through the turns, large walls will likely be required. In this event, the existing dry stack and masonry walls should be replaced with new MSE walls founded on bedrock. Bedrock appears to be within a few feet of the surface, and closely fractured, which should facilitate excavation for a wall foundation, if required.

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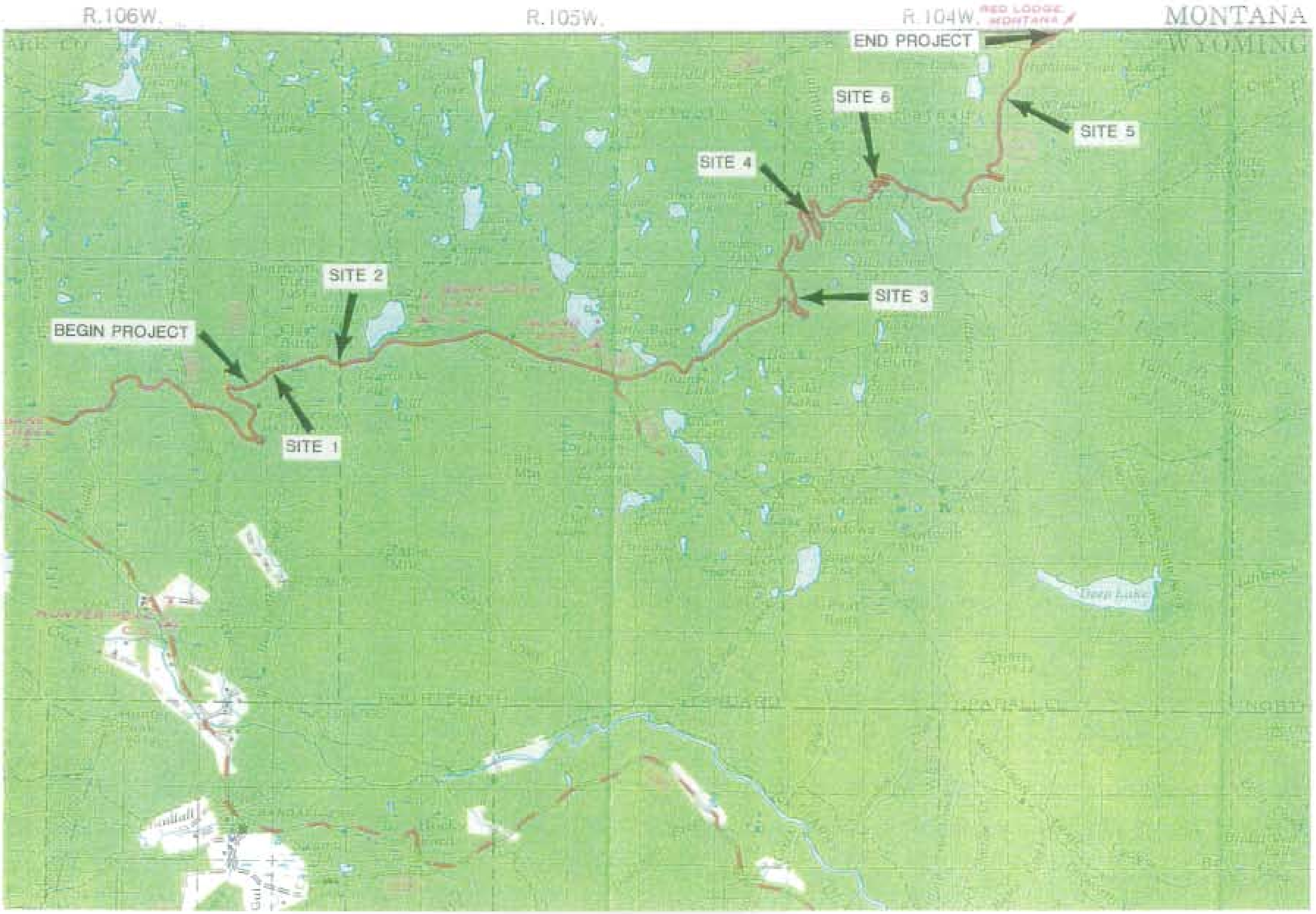


SCALE: 1/2" = 1 mile

Base Map taken from Shoshone National Forest, Forest Visitors Map
U.S. Department of Agriculture, 1969

Project No. FHAT0011	Federal Highway Administration Beartooth Highway, Wyoming	BEARTOOTH HIGHWAY SITE MAP	Figure 1
Woodward-Clyde International-Americas			

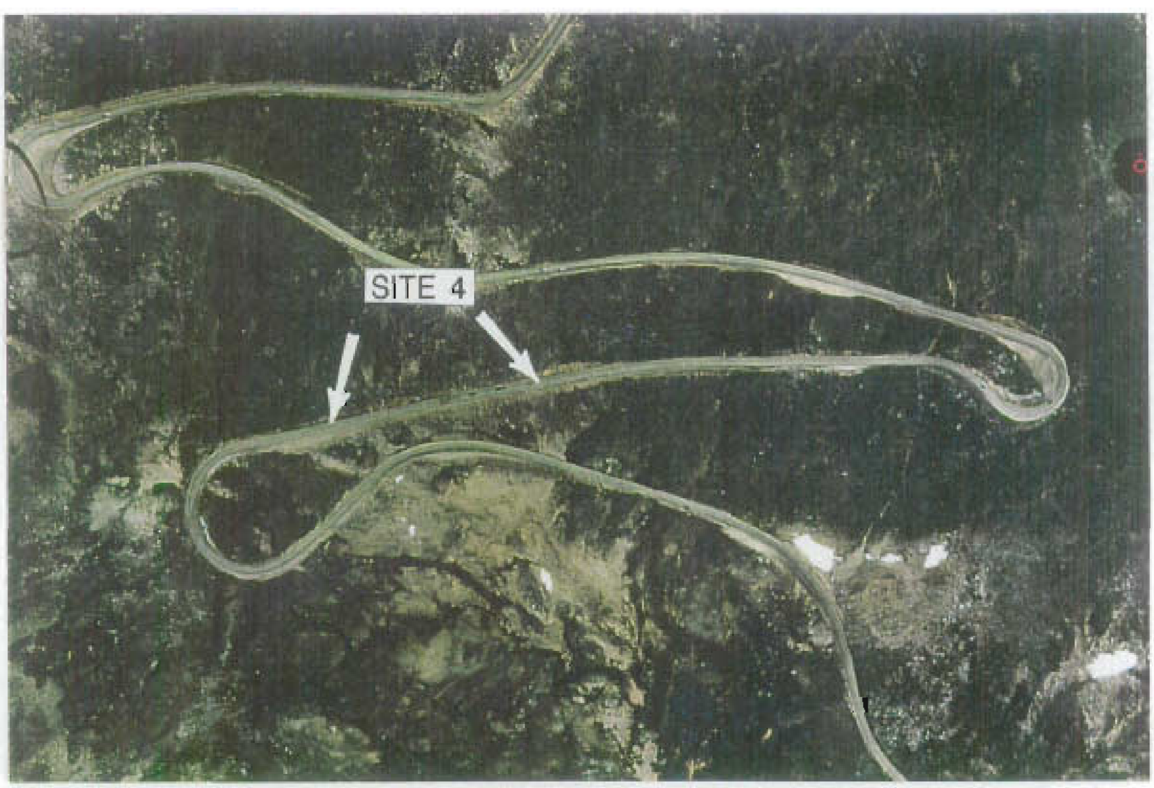
FIG-1.GRF 09/14/98 KSP

Project No. FHAT0011	Federal Highway Administration Beartooth Highway, Wyoming	SITE NUMBER 1 STA 39+800 TO 40+000	Figure 2
Woodward-Clyde International-Americas			

FIG-2.GRF / 09/14/98/ dlg

Project No. FHAT0011	Federal Highway Administration Beartooth Highway, Wyoming Woodward-Clyde International-Americas	SITE NUMBER 2 STA. 41+600 TO 42+000	Figure 3

FIG-3.GRF / 09/18/98/ dlg



Project No. FHAT0011	Federal Highway Administration Beartooth Highway, Wyoming	SITE NUMBER 4 STA 57+100 TO 57+300	Figure 5
Woodward-Clyde International-Americas			

FIG-5.GRF / 09/14/98/ dlg

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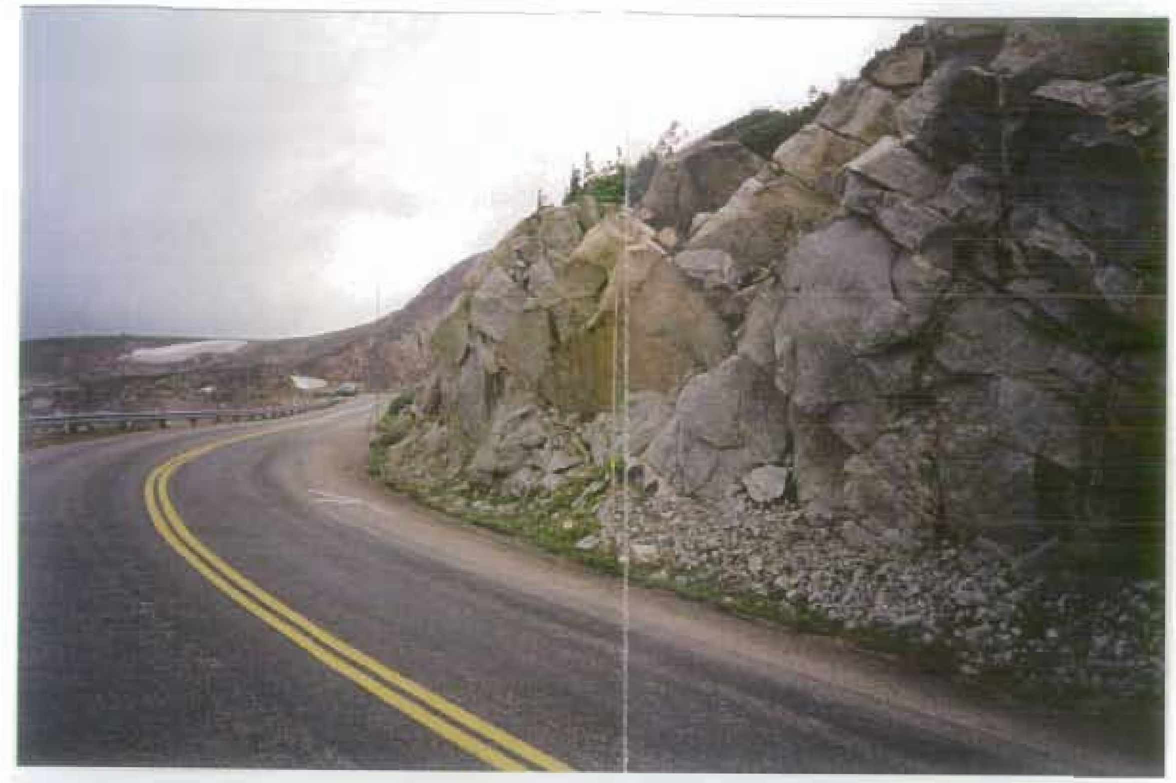
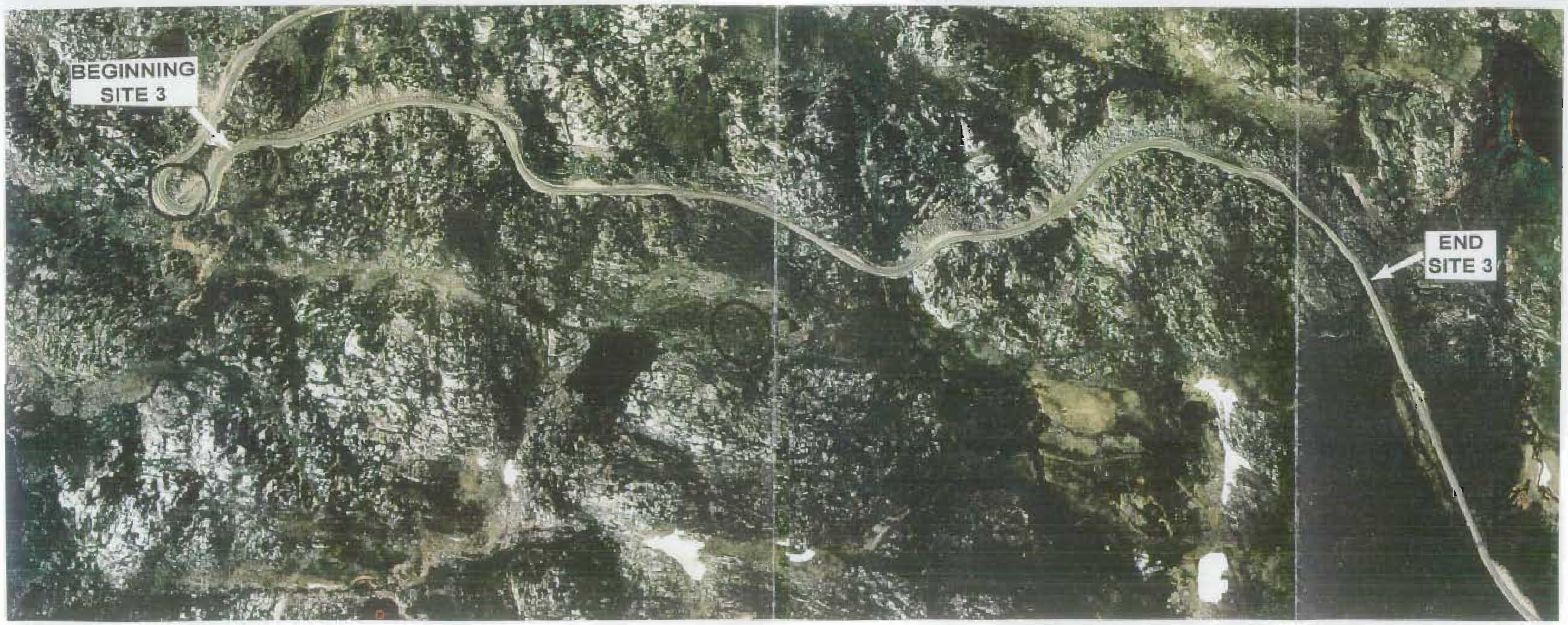
Project No. FHAT0011	Federal Highway Administration Beartooth Highway, Wyoming	SITE NUMBER 5 STA 67+250 TO 67+550	Figure 6
Woodward-Clyde International-Americas			

FIG-5.GRF 09/14/98 dlg

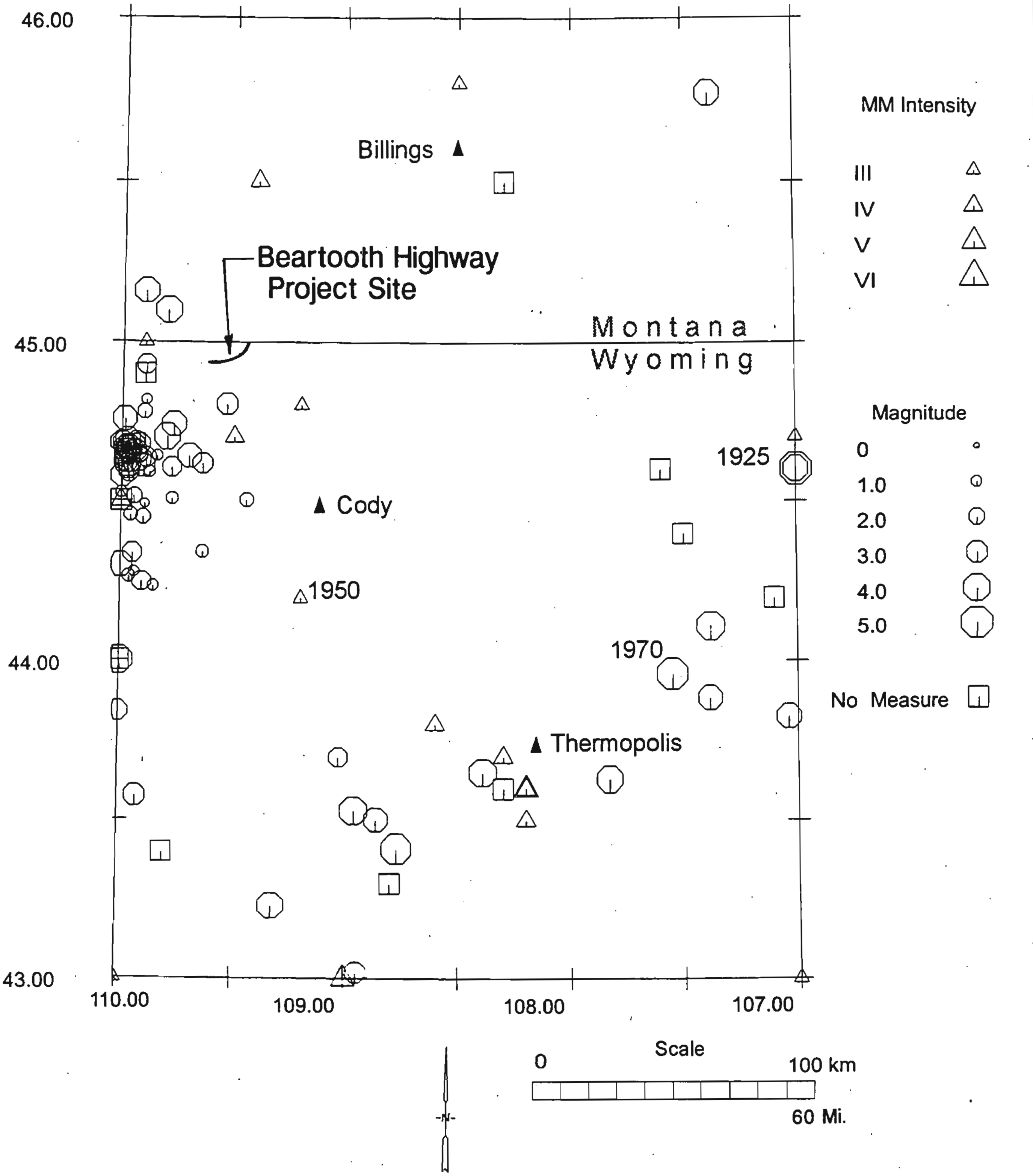
Project No. FHAT0011	Federal Highway Administration Beartooth Highway, Wyoming	SITE NUMBER 6 STA 60+500 TO 62+000	Figure 7
Woodward-Clyde International-Americas			

FIG-7.GRF / 09/14/98/ dlg





Project No. FHAT0011	Federal Highway Administration Beartooth Highway, Wyoming	SITE NUMBER 3 STA 53+400 TO 55+000	Figure 4
Woodward-Clyde International-Americas			



Earthquake Data Sources: National Earthquake Information Center and University of Utah

Project No. FHAT0011	Beartooth Highway	HISTORICAL SEISMICITY OF SITE REGION 1873 TO 1995	Figure A-1
Woodward-Clyde Consultants			